

Amendments to the Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims:

- 1 1. (Currently Amended) A linear method for performing head motion estimation from facial feature data, the method comprising the steps of:
 - 4 obtaining a first facial image and detecting a head in said first image;
 - 6 detecting position of ~~not more than~~ only four points P of said first facial image where $P = \{p_1, p_2, p_3, p_4\}$, and $p_k = (x_k, y_k)$;
 - 8 obtaining a second facial image and detecting a head in said second image;
 - 10 detecting position of ~~not more than~~ only four points P' of said first-second facial image where $P' = \{p'_1, p'_2, p'_3, p'_4\}$ and $p'_k = (x'_k, y'_k)$;
 - 12 and
 - 13 determining the motion of the head represented by a rotation matrix R and translation vector T using said points P and P' .

1 2. (Currently Amended) The linear method of claim 1, wherein
2 | said only four points P of said first facial image and said only
3 | four points P' of said second facial image include locations of
4 | outer corners of each eye and mouth of each respective first and
5 | second facial images.

1 3. (Original) The linear method of claim 1, wherein said
2 head motion estimation is governed according to:

3 $\mathbf{P}'_i = R\mathbf{P}_i + \mathbf{T}$, where $R = \begin{bmatrix} \mathbf{r}_1^T \\ \mathbf{r}_2^T \\ \mathbf{r}_3^T \end{bmatrix} = \begin{bmatrix} r_x \\ r_y \end{bmatrix}_{3 \times 3}$ and $\mathbf{T} = [T_1 \ T_2 \ T_3]^T$ represent camera
4 rotation and translation respectively, said head pose estimation
5 being a specific instance of head motion estimation.

1 4. (Currently amended) A linear method for performing head
2 motion estimation from facial feature data, the method comprising
3 the steps of:

4 obtaining a first facial image and detecting a head in said
5 first image;

6 detecting position of four points P of said first facial image
7 where $P = \{\mathbf{p}_1, \mathbf{p}_2, \mathbf{p}_3, \mathbf{p}_4\}$, and $\mathbf{p}_k = (x_k, y_k)$;

8 obtaining a second facial image and detecting a head in said
9 second image;

10 | detecting position of four points P' of said first-second
 11 | facial image where $P' = \{p'_1, p'_2, p'_3, p'_4\}$ and $p'_k = (x'_k, y'_k)$; and,
 12 | determining the motion of the head represented by a rotation
 13 | matrix R and translation vector T using said points P and P',
 14 | wherein said head motion estimation is governed according to:

15 $\mathbf{P}'_i = R\mathbf{P}_i + \mathbf{T}$, where $R = \begin{bmatrix} \mathbf{r}_1^T \\ \mathbf{r}_2^T \\ \mathbf{r}_3^T \end{bmatrix} = \begin{bmatrix} r_x \\ r_y \\ r_z \end{bmatrix}_{3 \times 3}$ and $\mathbf{T} = [T_1 \ T_2 \ T_3]^T$ represent camera

16 | rotation and translation respectively, said head pose estimation
 17 | being a specific instance of head motion estimation, and
 18 | wherein said head motion estimation is governed according to
 19 | said rotation matrix R, said method further comprising the steps
 20 | of:

21 | determining rotation matrix R that maps points \mathbf{P}_k to \mathbf{F}_k for
 22 | characterizing a head pose, said points $\mathbf{F}_1, \mathbf{F}_2, \mathbf{F}_3, \mathbf{F}_4$ representing three-
 23 | dimensional (3-D) coordinates of the respective four points of a
 24 | reference, frontal view of said facial image, and \mathbf{P}_k is the three-
 25 | dimensional (3-D) coordinates of an arbitrary point where

26 | $\mathbf{P}_i = [X_i \ Y_i \ Z_i]^T$, said mapping governed according to the relation:

27

28 | $R(\mathbf{P}_2 - \mathbf{P}_1) \propto [1 \ 0 \ 0]^T$

28 | $R(\mathbf{P}_6 - \mathbf{P}_5) \propto [0 \ 1 \ 0]^T$

29

30 wherein P_5 and P_6 are midpoints of respective line segments
 31 connecting points P_1P_2 and P_3P_4 and, line segment connecting points
 32 P_1P_2 is orthogonal to a line segment connecting points P_5P_6 , and
 33 \propto indicates a proportionality factor.

1 5. (Original) The linear method of claim 4, wherein
 2 components r_1 , r_2 and r_3 are computed as:

$$r_2^T(P_2 - P_1) = 0$$

$$r_3^T(P_2 - P_1) = 0$$

$$r_1^T(P_6 - P_5) = 0$$

$$r_3^T(P_6 - P_5) = 0$$

1 6. (Original) The linear method of claim 5, wherein
 2 components r_1 , r_2 and r_3 are computed as:

$$r_3 = (P_6 - P_5) \times (P_2 - P_1),$$

$$r_2 = r_3 \times (P_2 - P_1)$$

$$r_1 = r_2 \times r_3$$

1 7. (Original) The linear method of claim 4, wherein

$$\begin{bmatrix} P_i^T & 0^T & 0^T & 1 & 0 & 0 \\ 0^T & P_i^T & 0^T & 0 & 1 & 0 \\ 0^T & 0^T & P_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ T \end{bmatrix} = P'_i$$

3 each point pair yielding 3 equations, whereby at least four
4 point pairs are necessary to linearly solve for said rotation and
5 translation.

1 8. (Original) The linear method of claim 7, further
2 comprising the step of: decomposing said rotation matrix R using
3 Singular Value Decomposition (SVD) to obtain a form $R = USV^T$.

1 9. (Original) The linear method of claim 7, further
2 comprising the step of computing a new rotation matrix according to
3 $R = UV^T$.

1 10. (Original) A linear method for performing head motion
2 estimation from facial feature data, the method comprising the
3 steps of:

4 obtaining image position of four points P_k of a facial image;
5 determining a rotation matrix R that maps points P_k to F_k for
6 characterizing a head pose, said points F_1, F_2, F_3, F_4 representing
7 three-dimensional (3-D) coordinates of the respective four points
8 of a reference, frontal view of said facial image, and P_k is the

9 three-dimensional (3-D) coordinates of an arbitrary point where
10 $\mathbf{P}_i = [X_i \ Y_i \ Z_i]^T$, said mapping governed according to the relation:

11

$$R(\mathbf{P}_2 - \mathbf{P}_1) \propto [1 \ 0 \ 0]^T$$

$$R(\mathbf{P}_6 - \mathbf{P}_5) \propto [0 \ 1 \ 0]^T$$

13

14 wherein P_5 and P_6 are midpoints of respective line segments
15 connecting points P_1P_2 and P_3P_4 and, line segment connecting points
16 P_1P_2 is orthogonal to a line segment connecting points P_5P_6 , and
17 \propto indicates a proportionality factor.

1 11. (Original) The linear method of claim 10, wherein
2 components r_1 , r_2 and r_3 are computed as:

$$\mathbf{r}_2^T (\mathbf{P}_2 - \mathbf{P}_1) = 0$$

$$\mathbf{r}_3^T (\mathbf{P}_2 - \mathbf{P}_1) = 0$$

$$\mathbf{r}_1^T (\mathbf{P}_6 - \mathbf{P}_5) = 0$$

$$\mathbf{r}_3^T (\mathbf{P}_6 - \mathbf{P}_5) = 0$$

1 12. (Original) The linear method of claim 11, wherein
2 components r_1 , r_2 and r_3 are computed as:

$$3 \mathbf{r}_3 = (\mathbf{P}_6 - \mathbf{P}_5) \times (\mathbf{P}_2 - \mathbf{P}_1),$$

$$4 \mathbf{r}_2 = \mathbf{r}_3 \times (\mathbf{P}_2 - \mathbf{P}_1)$$

$$\mathbf{r}_1 = \mathbf{r}_2 \times \mathbf{r}_3$$

1 13. (Original) The linear method of claim 12, wherein a
 2 motion of head points is represented according to $\mathbf{P}' = \mathbf{R}\mathbf{P}_i + \mathbf{T}$

$$R = \begin{bmatrix} \mathbf{r}_1^T \\ \mathbf{r}_2^T \\ \mathbf{r}_3^T \end{bmatrix} = [\mathbf{r}_i]_{3 \times 3}$$

3 where represents image rotation, $\mathbf{T} = [T_1 \ T_2 \ T_3]^T$

4 represents translation, and \mathbf{P}'_i denotes a 3-D image position of four
 5 points \mathbf{P}_k of another facial image

1 14. (Original) The linear method of claim 13, wherein

$$\begin{bmatrix} \mathbf{P}_i^T & \mathbf{0}^T & \mathbf{0}^T & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \mathbf{r}_3 \\ \mathbf{T} \end{bmatrix} = \mathbf{P}'_i,$$

3 each point pair yielding 3 equations, whereby at least four
 4 point pairs are necessary to linearly solve for said rotation and
 5 translation.

1 15. (Original) The linear method of claim 14, further
 2 comprising the step of: decomposing said rotation matrix R using
 3 Singular Value Decomposition (SVD) to obtain a form $R = USV^T$.

1 16. (Original) The linear method of claim 15, further
2 comprising the step of computing a new rotation matrix according to
3 $R = UV^T$.

1 17. (Currently Amended) A program storage device readable by
2 machine, tangible embodying a program of instructions executable by
3 the machine to perform method steps for performing head motion
4 estimation from facial feature data, the method comprising the
5 steps of:

6 obtaining a first facial image and detecting a head in said
7 first image;

8 detecting position of ~~not more than~~ only four points P of said
9 first facial image where $P = \{p_1, p_2, p_3, p_4\}$, and $p_k = (x_k, y_k)$;

10 obtaining a second facial image and detecting a head in said
11 second image;

12 detecting position of ~~not more than~~ only four points P' of
13 said ~~first~~ second facial image where $P' = \{p'_1, p'_2, p'_3, p'_4\}$ and $p'_k = (x'_k, y'_k)$;
14 and,

15 determining the motion of the head represented by a rotation
16 matrix R and translation vector T using said points P and P' .

1 18. (Currently amended) The program storage device readable
2 by machine as claimed in claim 17, wherein said only four points P
3 of said first facial image and only four points P' of said second
4 facial image include locations of outer corners of each eye and
5 mouth of each respective first and second facial image.

1 19. (Original) The program storage device readable by
2 machine as claimed in claim 17, wherein said head motion estimation
3 is governed according to:

4
$$R = \begin{bmatrix} \mathbf{r}_1^T \\ \mathbf{r}_2^T \\ \mathbf{r}_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$$

$$\mathbf{P}'_i = R\mathbf{P}_i + \mathbf{T}, \quad \text{where} \quad \mathbf{T} = [T_1 \ T_2 \ T_3]^T \quad \text{represent}$$

5 camera rotation and translation respectively, said head pose
6 estimation being a specific instance of head motion estimation.

1 20. (Previously presented) A program storage device
2 readable by machine, tangible embodying a program of instructions
3 executable by the machine to perform method steps for performing
4 head motion estimation from facial feature data, the method
5 comprising the steps of:

6 obtaining a first facial image and detecting a head in said
7 first image;

8 detecting position of four points P of said first facial image
9 where $P = \{P_1, P_2, P_3, P_4\}$, and $P_k = (x_k, y_k)$;
10 obtaining a second facial image and detecting a head in said
11 second image;
12 detecting position of four points P' of said first-second
13 facial image where $P' = \{P'_1, P'_2, P'_3, P'_4\}$ and $P'_k = (x'_k, y'_k)$; and
14 determining the motion of the head represented by a rotation
15 matrix R and translation vector T using said points P and P',
16 wherein said head motion estimation is governed according to:

$$R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$$

17 $P'_i = RP_i + T$, where and $T = [T_1 \ T_2 \ T_3]^T$ represent

18 camera rotation and translation respectively, said head pose
19 estimation being a specific instance of head motion estimation, and
20 wherein said head pose estimation is governed according to
21 said rotation matrix R, said method further comprising the steps
22 of:

23 determining rotation matrix R that maps points P_k to F_k for
24 characterizing a head pose, said points F_1, F_2, F_3, F_4 representing three-
25 dimensional (3-D) coordinates of the respective four points of a
26 reference, frontal view of said facial image, and P_k is the three-

27 dimensional (3-D) coordinates of an arbitrary point where
28 $\mathbf{P}_i = [X_i \ Y_i \ Z_i]^T$, said mapping governed according to the relation:

29

$$R(\mathbf{P}_2 - \mathbf{P}_1) \propto [1 \ 0 \ 0]^T$$
$$R(\mathbf{P}_6 - \mathbf{P}_5) \propto [0 \ 1 \ 0]^T$$

31

32 wherein \mathbf{P}_5 and \mathbf{P}_6 are midpoints of respective line segments
33 connecting points $\mathbf{P}_1\mathbf{P}_2$ and $\mathbf{P}_3\mathbf{P}_4$ and, line segment connecting points
34 $\mathbf{P}_1\mathbf{P}_2$ is orthogonal to a line segment connecting points $\mathbf{P}_5\mathbf{P}_6$, and
35 \propto indicates a proportionality factor.

1 21. (Previously presented) The program storage device
2 readable by machine as claimed in claim 20, wherein components r_1 ,
3 r_2 and r_3 are computed as:

$$\mathbf{r}_2^T(\mathbf{P}_2 - \mathbf{P}_1) = 0$$
$$\mathbf{r}_3^T(\mathbf{P}_2 - \mathbf{P}_1) = 0$$
$$\mathbf{r}_1^T(\mathbf{P}_6 - \mathbf{P}_5) = 0$$
$$\mathbf{r}_3^T(\mathbf{P}_6 - \mathbf{P}_5) = 0$$

1 22. (Previously presented) The program storage device
2 readable by machine as claimed in claim 20, wherein components r_1 ,
3 r_2 and r_3 are computed as:

4 $\mathbf{r}_5 = (\mathbf{P}_6 - \mathbf{P}_5) \times (\mathbf{P}_2 - \mathbf{P}_1)$,

5 $\mathbf{r}_2 = \mathbf{r}_3 \times (\mathbf{P}_2 - \mathbf{P}_1)$

$\mathbf{r}_1 = \mathbf{r}_2 \times \mathbf{r}_3$

1 23. (Previously presented) The program storage device
2 readable by machine as claimed in claim 20, wherein

3
$$\begin{bmatrix} \mathbf{P}_i^T & \mathbf{0}^T & \mathbf{0}^T & 1 & 0 & 0 \\ \mathbf{0}^T & \mathbf{P}_i^T & \mathbf{0}^T & 0 & 1 & 0 \\ \mathbf{0}^T & \mathbf{0}^T & \mathbf{P}_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \mathbf{r}_3 \\ \mathbf{T} \end{bmatrix} = \mathbf{P}'_i$$
,

4 each point pair yielding 3 equations, whereby at least four
5 point pairs are necessary to linearly solve for said rotation and
6 translation.

24. (Previously presented) The program storage device
readable by machine as claimed in claim 23, further comprising the
steps of decomposing said rotation matrix R using Singular Value
Decomposition (SVD) to obtain a form $R = USV^T$.

25. (Previously presented) The program storage device
readable by machine as claimed in claim 23, further comprising the
steps of computing a new rotation matrix according to $R = UV^T$.